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University of Maryland at College Park

Center Office: IRIS Center, 2105 Morrill Hall, College Park, MD 20742
Telephone (301) 405-3110 • Fax (301) 405-3020

THE EFFECTS OF R&D, FOREIGN TECHNOLOGY PURCHASE, AND SPILLOVERS ON PRODUCTIVITY IN INDIAN FIRMS

June, 1994

Rakesh Basant and Brian Fikkert

Working Paper No. 116

This publication was made possible through support provided by the U.S. Agency for International Development, under Cooperative Agreement No. DHR-0015-A-00-0031-00.

Authors: Rakesh Basant, Gujarat lnstitute of Development Research, **Ahmedabad,** Indian, **and** Brian Fikkert, University of Maryland, College Park

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by

Rakesh Basant
Gujarat Institute of Development Research
Gota 382 481, Ahmedabad, India

and

Brian Fikkert
University of Maryland
Department of Economics
3105 Tydings Hall
College Park, MD 20742

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This paper is an abridged version of the authors' working paper at the United Nations University Institute of New Technologies (UNU-INTECH) in Maastricht (Basant and Fikkert (1993)), and Rakesh Basant acknowledges with thanks the financial and other support he received from UNU-INTECH. Brian Fikkert is also indebted to the center for Institutional Reform and the Informal Sector (IRIS) for its financial and institutional support of this work. Most of the research in this paper was conducted at the Economic Growth Center of-Yale University, and the authors are grateful to the Center for the use of its infrastructure. The authors also wish to express their thanks to the Institute for Studies in Industrial Development of New Delhi, India for providing the firm-level data. Helpful comments were received from Robert Evenson, Richard Levin, Ariel Pakes, T.N. Srinivasan, and Larry Westphal. Finally, thanks to Michael Ferrantino for all of his cooperation and advice with regards to data collection in India. Of course, all errors are solely the responsibility of the authors.

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IRIS Summary

Using panel data on Indian firms from 1974-1982, we provide estimates of the impact on output of Indian firms' R&D expenditures, of their purchases of foreign technology through licenses, and of international and domestic R&D spillovers. The estimated coefficients are then used to compute private rates of return to firms' R&D and technology purchase expenditures and to examine the impacts of India's policy of restricting foreign technology purchases to achieve domestic "technological self-reliance."

In every specification, the private rate of return to firms' foreign technology purchases is estimated to be quite high and statistically significant, achieving a value of 124 percent in even the most general specification. While the private return to firms' own R&D expenditures is estimated to be quite high also, it is lower than that to technology purchases and is often statistically insignificant, although even in the most general specification the estimated return is a highly respectable 80 percent. Furthermore, when firms are split into "scientific" (chemicals, drugs, and electricals) and "nonscientific" (all other industries) subsamples, it becomes clear that the gap by which the returns to technology purchases exceed those to R&D is much greater in the scientific

than in the nonscientific subsample, a result which accords with intuition since we expect Indian firms to be at the greatest disadvantage vis-a-vis the rest of the world in innovating in the sophisticated technologies which characterize the scientific group.

The results also provide evidence of both international and domestic R&D spillovers; however, the former are useful to firms only to the extent that they invest their own R&D resources in order to reverse engineer the technology developed by their foreign counterparts.

Finally, in every specification, R&D and technology purchase expenditures appear to be substitutes for one another in the production of knowledge. In related work it has been shown that such a condition is sufficient for India's restrictions on technology licensing to have achieved their desired goal of stimulating domestic R&D. Furthermore, the presence of domestic R&D spillovers indicates that the social return to indigenous R&D exceeds the private return, implying that some stimulus to firms' R&D expenditures is warranted. While an R&D subsidy would be the optimal policy, it is possible to show that restrictions on technology licenses would--in principle--be welfare improving whenever R&D and technology purchases are substitutes. However, in related work it is demonstrated that the stimulus to domestic R&D achieved by these regulations was extremely small in India, implying that the cost to India per unit of R&D stimulated may have been very high. In this light, India's recent relaxation of its technology licensing regulations is likely to provide large gains in productivity without sacrificing indigenous R&D efforts.

I. Introduction

Numerous studies have estimated the impacts of firms' own R&D expenditures on their productivity growth. Recently, several studies have also examined the influence on productivity of R&D spillovers between firms.[1] However, almost all econometric studies, new and old, analyze these linkages in the context of the developed countries. With the exception of Ferrantino (1992), we have not seen a similar study for less developed countries (LDCs) despite the current interest in knowledge capital as opposed to physical capital accumulation as the driving force behind growth (Grossman and Helpman (1991), Lucas (1988), and Romer (1986)).

Furthermore, the available studies from developed countries do not take into account a factor which is at least as important as R&D in the context of LDCs: the expenditures of LDC firms on disembodied technology through licensing agreements with foreign firms in developed countries. There has been a great deal of controversy as to how beneficial such technology purchases have been to LDCs, and India in particular has moved to restrict such agreements in hopes of stimulating indigenous R&D.[2]

The present paper presents estimates of the impact on productivity of firms' own R&D expenditures, their technology purchase (TP) expenditures, and foreign and domestic R&D spillovers using panel data for Indian manufacturing firms from the period

[1] See Griliches (1991), Mairesse and Sassenou (1991), and Mohnen (1990) for recent reviews.

[2] See Basant (1993) and Fikkert (1994) for reviews of this literature.

1974-75 to 1982-83 and R&D data from 9 countries. The results indicate that when all of the industries are examined together there are high, private rates of return to expenditures on both TP and R&D, although the effect of the latter is statistically insignificant in the most general specification in which both fixed effects and time dummies are included. Furthermore, the rate of return to TP exceeds that of R&D by 44 percent in the most general specification.

When firms are divided into scientific and nonscientific subgroups, interesting differences emerge.[3] In the fixed effects regressions with time dummies, the return to TP in the scientific group is estimated to be 166 percent, while the return to R&D falls to only 1 percent. In the nonscientific group, the corresponding regressions indicate returns to TP of 95 percent and to R&D of 64 percent. Taken together these results suggest that the potential for the greatest loss from India's restrictions on TP occurred in the scientific industries, a finding which accords with intuition since we would expect Indian firms to be at the greatest disadvantage vis-a-vis the rest of the world in innovating in these industries which employ sophisticated technology.

While the high returns to TP suggest that India's restrictions on technology licensing agreements imposed substantial costs on the Indian economy, the results confirm the findings of Basant (1993)

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[3]The "scientific" subgroup of firms consists of firms in the chemical and electronics industries while the "nonscientific" firms are in all other industrial categories. See Griliches and Mairesse (1984) for a similar grouping.

and Fikkert (1994) that R&D and TP are substitutes for one another in the production of knowledge. Fikkert (1994) shows that this substitutionary relationship is sufficient for the restrictions on TP to achieve their intended goal of stimulating domestic R&D and that, in principle, a tax on TP may be welfare improving whenever R&D and TP are substitutes and the marginal social return to R&D exceeds the marginal private return. In this light, the evidence provided here of domestic R&D spillovers suggests that a tax on TP purchases may be welfare improving in principle.[4] However, the policy simulations in Fikkert (1994) indicate that the aggregate elasticity of R&D to a tax on TP is quite small, implying that the cost to India of stimulating a unit of R&D by taxing TP is substantial.

The remainder of the paper is divided into four sections. The next section details the model to be used and discusses some of the estimation issues. Section III describes the data and the construction of the variables. The results of the estimations are presented in Section IV. Finally, Section V closes the paper with some remarks.

II. Model Construction and Estimation Techniques

II.A Model Specification

Most empirical studies in this literature postulate a simple extended Cobb-Douglas production function of the following type for firm i at time t:

[4] We also find evidence of international R&D spillovers.

$$Q_{it} = A\, e^{\lambda t}\, C_{it}^{\alpha}\, L_{it}^{\beta}\, M_{it}^{\theta}\, K_{it}^{\gamma}\, e^{\varepsilon_{it}} \qquad (1)$$

where Q is output measured in constant prices; λ is a parameter capturing the rate of disembodied technological change: α, β, θ and γ are output elasticities with respect to physical capital, labor, materials and knowledge capital, respectively; and ε is the error term reflecting the effects of unknown factors, data approximations, and other disturbances. The indices i and t denote the firm and time period respectively. Usually, constant returns to scale is assumed with respect to C, L, M, and K, which is equivalent to imposing $\alpha + \beta + \theta + \gamma = 1$. Estimation is usually performed by taking logs of equation (1) in order to linearize the estimation problem.

In most studies from developed countries, the knowledge capital for firm i, K_{it}, is a stock of the accumulated past R&D investments of firm i; however, K_{it} in the Indian context should also include stocks representing the technology which firm i purchases from others and stocks representing knowledge spillovers to firm i from external sources. Hence, we can write the expression for K_{it} as follows:

$$K_{it} = f(KO_{it}, KP_{it}, KD_{it}, KF_{it}) \qquad (2)$$

where KO_{it} is the stock of technical knowledge generated by firm i through its own R&D, KP_{it} is the stock of foreign technical knowledge purchased by firm i through technology licenses,[5] KD_{it} is a stock of spillover R&D emanating from other domestic firms in firm i's industry, and KF_{it} is a stock of spillover R&D emanating from foreign firms in firm i's industry.

Since there are several elements in the knowledge production function in equation (2) and since the interactive effect of each of these elements with one another is unknown, a general functional form for knowledge, K_{it}, is needed. Consequently, we have modified the production function in equation (1) so that it takes on the following form:

$$Q_{it} = A\, e^{\lambda t}\, e^{K_{it}}\, C_{it}^{\alpha}\, L_{it}^{\beta}\, M_{it}^{\theta}\, e^{\varepsilon_{it}} \tag{3}$$

where the knowledge stocks take the Generalized Leontief-Linear functional form of the following type (Fuss, McFadden and Mundlak, (1978)):

$$K_{it} = \sum_{s} \gamma_{s}\sqrt{Ks_{it}} + \sum_{s}\sum_{h} \gamma_{sh}\sqrt{Ks_{it}}\sqrt{Kh_{it}} \tag{4}$$

where s and h range over the letters O, P, F, and D. Note that $\gamma_{sh} = \gamma_{hs}$.

This specification permits KO_{it}, KP_{it}, KF_{it}, and KD_{it} to be substitutes or complements for one another. Furthermore, it avoids the problem of taking logarithms of the various inputs into the knowledge production function, for KO_{it} and KP_{it} are frequently zero.

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[5] In principle, there could also be technology purchases from other domestic firms. While we do not have data on such purchases, they are small relative to foreign technology purchases in the Indian context.

Nevertheless, there are two disadvantages to this specification. First, the inclusion of parameters for the interaction effects of the square roots of KO_{it}, KP_{it}, KF_{it}, and KD_{it} with themselves and with each other requires estimating more parameters than in those studies which estimate only a single coefficient for the effect of KO_{it} on output.[6] We alleviated this problem to a certain degree by omitting all of the terms in which **the square root of a variable interacts with itself, i.e. by** imposing $\gamma_{ss} = 0$.[7] Second, as mentioned earlier, it is common to impose constant returns to scale with respect to all the inputs. The more complicated specification used here does not easily lend itself to this constraint. Furthermore, given the lack of information about the structure of Indian industry, we felt it was inappropriate to impose such a constraint.

The logarithmic transformation of equation (3) after substituting for K_{it} from equation (4) gives us:

$$q_{it} = a + D_t + \alpha c_{it} + \beta l_{it} + \theta m_{it} \cdot \sum_s \gamma_s \sqrt{Ks_{it}} \;\square\; \sum_s \sum_h \gamma_{sh} \sqrt{Ks_{it}} \sqrt{Kh_{it}} \;\square\; \epsilon_{it} \quad (5)$$

where c_{it}, l_{it}, and m_{it} represent the natural logarithms of C,,, L,,, and M_{it} respectively, and λ_t has been replaced by year dummies, D_t, since such dummies impose less structure than a constant trend, A,, on any unobserved, period-specific effects. Later, estimates are **provided both with and without these time dummies.**

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[6]See the parameter y in equation (1).

[7]F-tests could not reject this restriction at the 5 percent level in any of our regressions.

Broadly, two versions of the general specification contained in equation (5) are explored in the paper. The first version does not include any foreign or domestic spillover variables. We report results both with and without time dummies. The second version includes either foreign or domestic spillover variables, but never both. Multicollinearity between the foreign and domestic spillover variables prevented us from including them together. Similarly, because the spillover variables are highly correlated with the time dummies, we, like many before us, are unable to include both the time dummies and spillover variables in the same equations.[8]

II.B Estimation Procedures

As is common with panel data, it is assumed that the error term in equation (5) can be decomposed into two independent terms:

$$\varepsilon_{it} = u_i + v_{it} \qquad (6)$$

where u_i corresponds to the permanent, unobserved heterogeneity across firms in their technologies, types of output, etc. and v_{it} is a period-specific shock for firm i, assumed to be independent across firms and over time.

All of the equations were estimated using random effects (RE) and fixed effects (FE) techniques. As is well known, FE is less efficient than RE because it uses only variation in the data within each firm through time. Unfortunately, RE assumes that u_i is uncorrelated with the regressors, which seems rather unlikely in the present context. Although u_i is unobserved by the

[8]For example, Table 2 of Mohnen's (1990) review of I3 empirical studies indicates that those studies which include spillover variables do not include any time trends or time dummies.

econometrician, its permanency would lead us to expect firms to observe u_i and to take the level of u_i into account when choosing their inputs. Because the FE procedure includes the firm-specific effects, u_i, as regressors rather than relegating them to the error term, it removes any biases which would result from correlation between u_i and the regressors.

However, the fact that FE only utilizes the variation of the data within each firm through time greatly reduces the variance of the regressors, introducing two familiar problems. First, any multicollinearity problems will be exacerbated. Mairesse and Sassenou, (1991) note that multicollinearity is particularly problematic with respect to physical and R&D capital, which tend to be aorrelated with time. As a result, including a time trend or time dummies frequently lowers the estimated coefficients on physical and R&D capital, something we shall see in a dramatic way in the estimates presented in this paper. Second, reducing the variance of the regressors tends to lower the signal-to-noise ratio for any given set of measurement errors, causing the estimates to bias towards zero.[9] Mairesse and Sassenou (1991) argue that the combined effect of these two problems is often so great that the RE specification *may* actually be preferred to FE in spite of RE's failure to remove the correlation between the regressors and u_i.

Researchers have found that constraining the estimates by imposing constant returns to scale to all of the parameters tends

[9]See Griliches and Mairesse (1984) and Mairesse and Sassenou (1991) for a further discussion of these issues.

to alleviate some of the FE problems. In fact, Mairesse and Sassenou (1991) note that without imposing this constraint, the vast majority of studies from developed countries have failed to find statistically significant coefficients for R&D in their FE estimates. As mentioned previously, constant returns to scale is not imposed in the estimates presented here.

It should also be pointed out that even though FE removes the correlation between the regressors and u_i, it is possible that firms also observe the period-specific shocks, v_{it}, before making their input choice at time t. If so, we would expect the input choices at time t to be functions of v_{it}, introducing correlation between the regressors and the error term. It is customary in this literature to assume that the inputs at time t are chosen before v_{it} is observed by the firm or that the firm never observes v_{it}, making the regressors at time t independent of this component of the error term. While this assumption may be problematic, there is reason to believe that it is less troublesome in the Indian context than in most cases. As part of its system of industrial planning, the Government of India regulated firm's physical capital stocks, rationed the foreign exchange needed to import raw materials and intermediate inputs, restricted foreign technology purchases, rationed scarce domestic inputs, and made it difficult to for firms to adjust their labor forces.[10] Hence, the ability of Indian firms to adjust their input levels to respond to period-specific shocks, v_{it}, would be reduced below that which would occur in a more market-

[10] See Fikkert (1994) for details.

oriented economy.

We provide RE and FE estimates of all of our equations. In every case, the Hausman statistic easily rejects the RE effects specification in favor of FE. However, the reader should keep in mind the problems with FE estimates mentioned above.

III. Sample Description and Variable Construction

III.A Sample Description

The firm-level data utilized in this study come from firms' annual reports for the nine-year period 1974-75 to 1982-83. For some of the firms only 5 of the 8 years of data were available. After removing firms not in the manufacturing sector, a total of 4949 observations remained. We felt that some cleaning of outliers was necessary since we expect that many of the variables, particularly capital, are subject to measurement error. Two basic steps were involved in this cleaning process. First, following Hall and Mairesse **(1992)**, we removed all observations for which the capital-labor ratio was outside of three times the inter-quartile range (the difference between the 75 percent value and the 25 percent value) above or below the median. This removed 268 observations, or 5.4 percent of the sample. Second, we removed all observations which had either output, capital, labor, or materials more than 300 percent above or less than 90 percent below each **firm's** average for each of these variables, where the average was calculated after removing the highest and lowest values of these variables for each firm. This second step removed only 24 more observations. Furthermore, only 5 of these 24 observations were deleted due to extreme values of output (0.1 percent of the sample), so the sample does not suffer from sample selection bias due to selecting on the basis of the value of the dependent variable. The remaining sample thus includes 4657 observations from 787 firms or 94 percent of the original data set, a number similar to the 96.2 percent retained by Hall and Mairesse (1992).

The firms cover the broad sweep of the manufacturing sector: 10.3 percent of the observations come from food processing, 9.7 percent from metals, 19.0 percent from chemicals and drugs, 23.7 percent from textiles, 7.1 percent from transportation, 10.0 percent from electronics, 7.7 percent from machinery, 5.9 percent from non-metallic minerals, 5.0 percent from paper and wood, and 1.5 percent from rubber products.

III.B Variable Construction

Output, the dependent variable in all of our regressions, was constructed by deflating the value of firms' reported output to constant 1980 rupees usiny wholesale price deflators at the three-digit, industrial classification level as reported in H.L Chandhok, et. al. (1990).

In order to construct the labor variable, each firm's total labor costs were divided by the average wage rate in the firm's industry for that year. These average wages were computed by dividing each industry's total labor costs by its total number of labor hours using the industrial-level data reported in the Annual Survev of Industries of India for various years.

Firms' expenditures on the purchase of materials were deflated to constant 1980 Rupees using industry-specific, input-deflators which were constructed by weighting output-price indices with coefficients from the Indian input-output matrix reported in National Accounts Statistics: Input-Output Transactions Table 1973-1974.

Firms' book values for physical capital were converted into net capital stocks expressed in constant 1980 Rupees by assuming 6 percent depreciation and employing the perpetual inventory method. See Appendix A for details.

Following earlier studies, the knowledge capital generated by the firm on its own, KO, was calculated by applying the perpetual inventory method to annual R&D expenditures assuming a 15 percent rate of depreciation and a one-year lag in the impact of R&D on. output?[11] See Appendix B for details.

Firms report for each year their expenditures on disembodied technology acquired through licenses with foreign companies. These flows were used to construct a stock of purchased technology, KP, again assuming a 15 percent rate of depreciation and a one-year lag in the impact of technology purchases on output. See Appendix B for details.

A number of ways of constructing spillovers have been employed in the literature, most using either R&D or patents as the proxy for the aggregate knowledge stocks.[12] The present study utilizes

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[11] For example, see Hall and Mairesse (1992).

[12] See Griliches (1991) for a survey.

the R&D conducted by the rest of the world in firm i's industry in order to create the foreign spillover stock, KF, for firm i.[13] In creating this stock, we felt it was important to account for the fact that not all foreign technology is equally relevant in India. For example, it is possible that agricultural production in the United States is more similar than that in Japan to agricultural production in India. This would be the case if crop mixtures, soil qualities, climates, scales of production, factor prices, etc. were more alike for the United States and India than they were for Japan and India. If this is the case, then we would expect greater spillovers from the United States' agricultural equipment industry's innovations than from Japan's, and we should adjust the United States' R&D to take these different levels of relevance into account.

To that end, indices of relevance, REL_{jc}, were constructed to weight the R&D emanating from industry j in country c, R,,. As described in detail in Appendix C, REX,, is the ratio of the number of patents granted by India to inventors in industry j from country c to the number of patents granted by country c to inventors in industry j from country c. In other words, we are assuming that higher levels of patenting in India indicates higher levels of relevance of the technology to India. REL_{jc} is normalized so that it adds up to 1 within an industry. Thus, the flow of R&D

[13] The "rest of the world" is proxied by 8 developed countries for which data was available from an unrelated project at Yale University. These 8 countries--Belgium, France, Japan, the Netherlands, Switzerland, United Kingdom, United States, and West Germany--account for the vast majority of world R&D.

spillovers from the rest of the world in industry j is the sum over c of $REL_{jc}R_{jc}$. Using these flows and the perpetual inventory method, a stock of world spillover technology was constructed, denoted by KF. See Appendix C for details.

The domestic spillover stock, KD, for firm i was constructed by applying the perpetual inventory method to flows of R&D conducted by Indian firms other than firm i in firm i's industry. See Appendix C for details,

Table 1 provides the means and standard deviations of all of the variables.

Table 1

SAMPLE MEANS AND STANDARD DEVIATIONS OF VARIABLES

	ALL FIRMS	SCIENTIFIC FIRMS	NON-SCIENTIFIC FIRMS
VARIABLES	MEAN (STANDARD DEVIATION)	MEAN (STANDARD DEVIATION)	MEAN (STANDARD DEVIATION)
Number of Observations	4,657	1,371	3,286
Output (Q) '000 Rupees	202.153 (339,155)	215,289 (332,245)	196,672 (341,898)
Net Physical Capital (C) '000 Rupees	112,235 (295,413)	95,550 (162,904)	119,197 (335,348)
Materials(M) '000 Rupees	103,768 (185,396)	108,454 (200,193)	101.813 (178,856)
R&D Capital(KO) '000 Rupees	814 (3,139)	1,281 (3,019)	617 (3,168)
Licensed Technology Capital (KP) '000 Rupees	1,534 (5,504)	1,443 (4,251)	1,572 (5,950)
Foreign Spillovers capital (KF) '000 $	629,731 (1,011,590)	1,015,328 (1,184,137)	468,850 (881,860)
Domestic Spillovers capital (KD) '00 Rupees	1,906,590 (2,502,039)	3,406,952 (2,823,041)	1,280,602 (2,053,714)

Note: All variables are in constant 1980 prices.

IV. Estimation Results

Tables 2-5 detail the results from the RE and FE estimations. In each case the Hausman statistic is provided for the test of the

RE versus the FE effects specification. Each table also reports the implied private, marginal, internal rate of return to R&D and TP expenditures for each set of RE and FE estimates.[14]

Turning first to the regressions without the spillover variables for the complete sample of firms, Table 2 indicates that both with and without time dummies, the direct effect of the firms' own R&D stocks (KO) in the RE regressions is positive and Significant, yielding a rate of return of 170 percent without and 130 percent with time dummies in the overly-conservative case of zero-growth in output: however, the Hausman statistic easily rejects the RE specification, so we need to consider the FE estimates which are less subject to simultaneity problems from unobserved firm heterogeneity, as was discussed -earlier,

The FE estimate of the KO coefficient without time dummies

[14] If the lag time between the expenditure on R&D (or TP) and its effect on output is θ, and the decay rate for knowledge is 6, then using equation (5) we see that the internal rate of return, r, to a unit expenditure on R&D at time -8, denoted by $R_{-\theta}$, must solve the following equation:

$$\int_0^{\infty} \left(\frac{\partial Q_0}{\partial R_{-\theta}}\right) e^{-r(t+\theta)+(g-\delta)t}\, dt = 1$$

where Q_0 is the output at time 0 and g is the growth rate of output. We evaluate this expression at the mean levels of Q, KO, KF, and KD in the sample, and solve the expression numerically for r. KP is set equal to zero because so few firms have positive values of both KO and KP and because we want to determine the rates of return to R&D and TP in isolation of one another. Figures are provided assuming $g = 0$ and $g = 0.06$, the latter being the average annual growth rate of output for 1975/76-1979/80 for the firms in the sample. Exactly the same procedure was used to calculate the rate of return to explicit expenditures on TP, those unobserved costs of winning government approval of the technology license being ignored.

indicates lower returns than its RE counterpart, although the effect of KO is still quite high and significant. However, when time dummies are added-the coefficient on KO falls by almost two-thirds and becomes insignificant. Similar patterns are present for the physical capital estimates. As mentioned earlier, both of these findings are consistent with nearly every study of this sort.[15] With ideal data, the patterns would be attributed to firms' choosing R&D and physical capital as functions of the unobserved firm effects and/or the period-specific effects represented by the time dummies. However, as mentioned above, measurement errors and multicollinearity between the upward-trending physical and R&D capital and the time dummies are also likely to be important factors in the lower FE estimates for both R&D and physical capital.

Support for this explanation may be deduced from the fact that in all of the tables the coefficients on labor and materials--variables which are easier to measure than the physical and R&D capital stocks and which are less likely to be consistently trending upwards--do not change very much as we move from the RE to the FE estimates or as we add time dummies. Furthermore, if the endogenous choice of the regressors as functions of unobserved firm heterogeneity and/or the time effects is the primary reason for the discrepancy between the estimates, we would expect to see the parameter estimates for labor and materials change also. In a

[15]See Mairesse and Sassenou (1991.) and Hall and Mairesse (1992).

market-oriented economy, labor and materials levels are more flexible than levels of capital and hence more endogenous in the short-to medium-run: hence, we would expect them to respond more rather than less to any exogenous factors. The short-run flexibility of labor and materials is substantially reduced in India due to the government's industrial regulations, Nevertheless, labor and materials are certainly no less flexible than capital, and if endogeneity is the cause of the change in the capital coefficients we would expect the labor and materials coefficients to change once the heterogeneity and period effects are removed from the error term and included as regressors.

We should not overlook in all of this that even if one relies on the FE estimates with the time dummies, the implied rate of return to R&D, while insignificant, is a highly respectable 80 percent even in the case of zero-growth in output.

Tables 3-4 provide the results for the scientific and nonscientific subsamples. As with the regressions for the complete set of firms, moving from RE to FE lowers the returns to R&D, and adding time dummies to the FE estimations renders the estimated coefficients on R&D insignificant. These patterns are particularly strong for the scientific firms, where the rate of return in the FE estimation with time dummies falls to only 1 percent, as compared with 64 percent for the nonscientific firms. These lower returns to R&D in the scientific subgroup might be expected due to the greater complexity of technology in such areas.

In all of the estimates in Tables 2-4, the stock of technology purchases, KP, is significant regardless of the estimation technique and specification. Furthermore, the rates of return to such expenditures are high and relatively stable across specifications, ranging from a low of 124 percent in the FE estimates with time dummies for the entire sample of firms (Table 2) to a high of 184 percent in the RE estimates without time dummies for the scientific subsample (Table 3). These results are much more robust than those for R&D in either this study or in similar studies from developed countries.

A comparison of Tables 3-4 indicates that the return to TP is much higher in the scientific than in the nonscientific sectors in every specification. This result is consistent with the findings in Evenson (1991) that technologies in the scientific industries appear to be more transferable internationally than technologies in the nonscientific industries.

Table 5 reports the results when the spillover variables are included. As mentioned previously, multicollinearity prevented us from including both foreign and domestic spillovers in the same equation and from including time dummies with the spillover variables. Again, the Hausman statistic easily rejects the RE in favor of the FE specification. The coefficients for KO and KP are jointly significant in all of the FE estimates, and the implied rates of return are quite high.

It is interesting to note in Table 5 that the interaction between each firm's R&D stock, KO, and foreign spillovers, KF, is positive and significant. This confirms the findings of Basant

(1993) and Fikkert (1994) that foreign spillovers are a complement to firms' R&D. Such spillovers apparently enhance the possibilities for the adaptation and reverse engineering of unlicensed foreign inventions. Indeed, it appears that without such adaptive R&D, firms are unable to benefit from foreign spillovers, the direct effects of the foreign spillovers being insignificant.

In contrast, Table 5 indicates that the direct effect of domestic spillovers, ED, is significant in both the FE and RE estimations, while the interaction of KO and KD is insignificant. Domestic spillovers, consisting of the R&D of each firm's competitors in India, are presumably more appropriate to Indian conditions than the inventions developed on foreign soils, which make up the foreign spillover variable, KF. Hence, domestic spillovers should require less adaptive R&D before they can be utilized than would foreign spillovers, resulting in less complementarity between domestic spillovers and each firm's R&D. In addition, since foreign inventions are normally at a higher level of sophistication than domestic inventions, we would expect that the reverse engineering of foreign inventions would require more R&D than would similar "borrowing" of the domestic inventions produced by others.

The estimates in Tables 2-5 support the findings of Basant (1993) and Fikkert (1994) that R&D and TP expenditures are substitutes in the production of knowledge, contradicting the assertions of several previous studies.[16] Although it is often insignificant, the coefficient for the interaction between R&D and TP is negative in every specification, implying that the two variables are substitutes in the sense that each variable lowers the marginal productivity of the other. As mentioned earlier, such a condition is necessary for India's regulations on technology licensing to achieve their desired goal of stimulating indigenous R&D efforts."

V. Concluding Remarks

Space does not permit an extensive comparison of the results from this study with those from developed countries: however, the majority of such studies have found relatively high rates of return in the range of 20-50 percent, although results lying substantially above and below this range are common.[18] The corresponding estimates from our study are somewhat higher than this for the complete sample and the nonscientific subsample, and somewhat lower for the scientific subsample.

The estimated rates of return to TP expenditures are much higher than most estimates of the returns to R&D from either the

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[16]See, for example, Braga and Wilmore (1991); Deolalikar and Evenson (1989); Katrak (1991), (1990), (1989), (1985); Kumar (1987); and Mohnen and Lepine (1991). Basant (1993) and Fikkert (1994) discuss the problems with these previous studies.

[17]See Dasant (1993) and Pikkert (1994) for a further discussion of these issues.

[18]See Basant and Fikkert (1993) for a review of studies from developed countries.

developed countries or India. Even in the nonscientific subsample where the productivity of TP appears to be somewhat lower, the FE estimates with time dummies indicate significant returns of 64 percent even in the case of zero growth in output. Contrary to the pessimistic views of many, there do appear to be real opportunities for LDCs to obtain high yields to their investments in technology licensing agreements.

Our results differ from those of Ferrantino (1992) who found no systematic impact of Indian firms' R&D and TP expenditures on their productivity. There are several possible reasons for our contrasting results. First, Ferrantino estimated a cost function indirectly from the conditional factor demand equations for capital and labor, requiring him to assume that Indian firms were making cost-minimizing choices for both capital and labor. Such an assumption seems inappropriate to us, since the Indian government's capacity licensing regulations severely hampered Indian firms from adjusting their capital stocks at will.[19] Second, Ferrantino did not correct for firm-level heterogeneity through either RE or FE techniques. Third, Ferrantino did not have access to some of the pre-sample information with regards to firms' TP expenditures which we had, creating increased difficulties for him in creating his KP stocks.[20]

From a policy perspective, the overall evidence suggests that there are substantial returns to be had from increasing the levels

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[19]See Fikkert (1994) for details of these policies.

[20]See Appendix B for details.

of both R&D and TP expenditures. In addition, the finding of Basant (1993) and Fikkert (1994) thatR&D and TP are substitutes is confirmed, suggesting that India's technology licensing regulations had their desired effect of stimulating R&D, a legitimate goal given the apparent externalities from the domestic R&D spillovers. However, these regulations may have had a substantial cost, the private returns to TP expenditures being much higher than those to R&D. Estimates of these private costs of promoting R&D through technology restrictions are provided in Fikkert (1994). Finally, the presence of international spillovers indicates opportunities to imitate foreign inventions for those Indian firms willing to expend their own R&D resources.

TABLE 2

PRODUCTION FUNCTION ESTIMATES WITHOUT SPILLOVERS
ALL FIRMS

VARIABLES	FE NO TIME DUMMIES	RE NO TIME DUMMIES	FE WITH TIME DUMMIES	RE WITH TIME DUMMIES
Capital (c)	$.777 \times 10^{-1}$ (5.70)	$.951 \times 10^{-1}$ (10.5)	$.554 \times 10^{-1}$ (4.03)	$.969 \times 10^{-1}$ (10.4)
Labor (l)	.287 (27.9)	.272 (32.4)	.277 (22.0)	.259 (27.7)
Materials (m)	.638 (76.5)	.608 (88.3)	.631 (76.4)	.606 (88.8)
R&D Capital Stock ($\sqrt{KO}$)	$.849 \times 10^{-3}$ (3.08)	$.133 \times 10^{-2}$ (5.23)	$.275 \times 10^{-3}$ (0.990)*	$.689 \times 10^{-3}$ (2.68)
Purchased Technology Stock ($\sqrt{KP}$)	$.912 \times 10^{-3}$ (3.64)	$.119 \times 10^{-2}$ (5.61)	$.873 \times 10^{-3}$ (3.55)	$.116 \times 10^{-2}$ (5.52)
$\sqrt{KO} \times \sqrt{KP}$	$-.482 \times 10^{-5}$ (-1.35)*	$-.967 \times 10^{-5}$ (-3.19)	$-.412 \times 10^{-5}$ (-1.17)*	$-.779 \times 10^{-5}$ (-2.61)
Constant	-	2.27 (27.1)	-	2.28 (27.2)
R^2	.801	.870	.808	.873
Hausman Statistics	-	102.4	-	108.9
ROR to RD with g=0	142%	170%	80%	130%
ROR to TP with g=0	126%	142%	124%	140%
ROR to RD with g=.06	144%	172%	82%	132%
ROR to TP with g=.06	128%	144%	126%	142%

TABLE3

PRODUCTION FUNCTION ESTIMATES WITHOUT SPILLOVERS
SCIENTIFIC FIRMS

VARIABLES	FE NO TIME DUMMIES	RE NO TIME DUMMIES	FE WITH TIME DUMMIES	RE WITH TIME DUMMIES
Capital (c)	.216 (7.12)	$.983 \times 10^{-1}$ (5.48)	.153 (5.05)	.107 (5.86)
Labor (l)	.227 (10.3)	.278 (15.1)	.172 (6.04)	.241 (11.5)
Materials (m)	.724 (35.8)	.625 (37.5)	.693 (35.3)	.617 (38.4)
R&D Capital Stock ($\sqrt{KO}$)	$.138 \times 10^{-2}$ (2.96)	$.149 \times 10^{-2}$ (3.32)	$.322 \times 10^{-4}$ (0.070)*	$.969 \times 10^{-4}$ (.221)*
Purchased Technology Stock ($\sqrt{KP}$)	$.183 \times 10^{-2}$ (3.64)	$.251 \times 10^{-2}$ (4.62)	$.190 \times 10^{-2}$ (3.33)	$.237 \times 10^{-2}$ (4.60)
$\sqrt{KO} \times \sqrt{KP}$	$-.496 \times 10^{-5}$ (-.524)*	$-.237 \times 10^{-4}$ (-3.04)	$-.334 \times 10^{-5}$ (-.370)*	$-.150 \times 10^{-4}$ (-2.01)
Constant	-	2.00 (11.7)	-	2.13 (12.9)
R^2	.759	.836	.782	.850
Hausman Statistics	-	100.0	-	50.5
ROR to RD with g=0	146%	150%	1%	23%
ROR to TP with g=0	164%	184%	166%	181%
ROR to RD with g=.06	148%	153%	6%	28%
ROR to TP with g=.06	166%	186%	168%	183%

Notes:
1. "ROR" is the private, marginal, internal rate of return.
2. Figures in parentheses are t-values.
3. "*" indicates NOT significant at .10 level in a two-tailed test.
4. All Hausman statistics significant at .01 level.

TABLE 4

PRODUCTION FUNCTION ESTIMATES WITHOUT SPILLOVERS
NONSCIENTIFIC FIRMS

VARIABLES	FE NO TIME DUMMIES	RE NO TIME DUMMIES	FE WITH TIME DUMMIES	RE WITH TIME DUMMIES
Capital (c)	.354 x 10^{-1} (2.45)	.940 x 10^{-1} (9.40)	.239 x 10^{-1} (1.63)	.915 x 10^{-1} (8.85)
Labor (l)	.301 (27.1)	.283 (31.0)	.315 (23.4)	.285 (28.1)
Materials (m)	.617 (71.8)	.593 (82.5)	.612 (71.5)	.592 (82.3)
R&D Capital Stock ($\sqrt{KO}$)	.320 x 10^{-3} (.924)*	.689 x 10^{-3} (2.15)	.147 x 10^{-3} (.420)*	.470 x 10^{-3} (1.45)*
Purchased Technology Stock ($\sqrt{KP}$)	.498 x 10^{-3} (1.90)	.725 x 10^{-3} (3.30)	.498 x 10^{-3} (1.92)	.725 x 10^{-3} (3.32)
$\sqrt{KO}$ x $\sqrt{KP}$	-.956 x 10^{-6} (-.249)*	-.438 x 10^{-5} (-1.34)*	-.102 x 10^{-5} (-.267)*	-.394 x 10^{-5} (-1.21)
Constant	-	2.46 (25.9)	-	2.59 (26.9)
R^2	.759	.891	.833	.892
Hausman Statistics	-	95.5	-	113.8
ROR to RD with g=0	102%	146%	64%	124%
ROR to TP with g=0	95%	115%	95%	115%
ROR to RD with g=.06	105%	149%	67%	127%
ROR to TP with g=.06	98%	118%	98%	118%

Notes :
1. "ROR" is the private, marginal, internal rate of return.
2. Figures in parentheses are t-values.
3. "*" indicates NOT significant at .10 level in a two-tailed test.
4. All Hausman statistics significant at .01 level.

TABLE 5
PRODUCTION FUNCTION ESTIMATES WITH SPILLOVERS
ALL FIRMS

VARIABLES	FE: DOMESTIC SPILLOVERS	RE: DOMESTIC SPILLOVERS	FE: FOREIGN SPILLOVERS	RE: FOREIGN SPILLOVERS
Capital (c)	.707 x 10^{-1} (5.14)	.979 x 10^{-1} (10.8)	.758 x 10^{-1} (5.54)	.982 x 10^{-1} (10.9)
Labor (l)	.274 (25.3)	.264 (31.1)	.286 (26.2)	.271 (32.4)
Materials (m)	.639 (76.7)	.610 (88.7)	.638 (76.5)	.608 (88.6)
R&D Capital Stock (√KO)	.720 x 10^{-3} (2.13)	.102 x 10^{-2} (3.17)	.476 x 10^{-3} (1.40)*	.930 x 10^{-3} (2.90)
Purchased Technology Stock (√KP)	.109 x 10^{-2} (3.41)	.138 x 10^{-2} (4.93)	.678 x 10^{-3} (1.80)	.123 x 10^{-2} (3.82)
√KO x √KP	-.427 x 10^{-5} (-1.16)*	-.821 x 10^{-5} (-2.68)	-.661 x 10^{-5} (-1.79)	[illegible] x 10^{-5} (-2.89)
Domestic R&D Spillovers (√KD)	.407 x 10^{-4} (3.50)	.435 x 10^{-4} (4.98)	-	-
√KO x √KD	.144 x 10^{-7} (.082)*	.571 x 10^{-7} (.347)*	-	-
√KP x √KD	-.103 x 10^{-6} (-.726)*	-.195 x 10^{-6} (-1.51)*	-	-
Foreign R&D Spillovers (√KF)	-	-	-.195 x 10^{-4} (-0.366)*	.899 x 10^{-4} (4.44)
√KO x √KF	-	-	.634 x 10^{-6} (1.89)	.261 x 10^{-6} (.874)*
√KP x √KF	-		.403 x 10^{-6} (1.11)*	-.217 x 10^{-6} (-.744)*
Constant	-	2.23 (26.5)	-	2.19 (25.7)
R^2	.802	.871	.801	.871
Hausman Statistics	-	93.8	-	96.9
Joint Significance of all √KO Coefficients	.06	Not Significant	.01	Not Significant
Joint Significance of all √KP Coefficients	.01	.02	.01	.01
ROR to RD with g=0	134%	157%	143%	157%
ROR to TP with g=0	130%	141%	126%	137%
ROR to RD with g=.06	136%	159%	145%	160%
ROR to TP with g=.06	133%	143%	129%	139%

Notes:
1. "ROR" is the private, marginal, internal rate of return.
2. Figures in parentheses are t-values.
3. "*" indicates NOT Significant at .10 level in a two-tailed test.
4. All Hausman Statistics significant at .01 level.

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Appendix A: Construction of Firms' Physical Capital Stocks

In order to construct a net physical capital stock in constant 1980 Rupees, we first calculated the average age, AA, of each firm's capital stock by assuming that the full depreciation of capital takes 16 years for accounting purposes and employing the following formula:

$$(GC_{75}/16)*AA = AD_{75} \tag{A.1}$$

where CC_{75} is gross capital and AD_{75} is the accumulated depreciation of capital in the first year of data, 1975, GC_{75} and AD,, being obtained from each firms' reported values.

Using the value of AA obtained from equation (A.1), a deflator was constructed for each firm's capital stock to deflate from the year '1975-M' to the year '1975'. If this aapital deflator for firm i is called CD_i and if the depreciation rate is 6 percent, then the net capital stock for firm i in 1975, C_{75} is equal to:

$$C_{75} = (GC_{75}/CD_i)*(1-.06)^{AA} \tag{A.2}$$

If PC,, is the price deflator for investment for 1976, then C_{76} for firm i is:

$$C_{76} = C_{75}(1-.06) + (GC_{76}-GC_{75})/PC_{76} \tag{A.3}$$

Equation (A.3) was also used to compute C_{it} for the subsequent years, giving a capital-stock series net of depreciation and expressed in constant 1980 rupees.

Appendix B: Construction of Firms' R&D and TP Stocks

The knowledge capital at time t generated by firm i on its own, KO_{it}, can be approximated by past R&D investments. Following earlier studies, a perpetual inventory method was used to construct KO_{it} as follows:

$$KO_{it} = (1-\delta)KO_{it-1} + RD_{it-1} \qquad \text{(B.1)}$$

where RD_{it-1} is the expenditure on research and development at time t-l and δ is the rate of depreciation to technical knowledge, assumed to be 15 percent.[21] These R&D expenditures were deflated using the average of the wage and capital investment price deflators obtained from Chandhok et. al. (1990).

In order to employ equation (B.1), it is necessary to know the value of KO_{it} in thc initial year of the data, 1975. Since most firms in India did not do R&D prior to 1975, it was assumed that firms which did not report R&D expenditures in the first year of the data did not undertake any R&D during the preceding period. Consequently, the initial, R&D stock for these firms was assumed to be zero.

In order to construct the initial R&D stock for the firms which did report R&D in the first year of the data it was necessary to know the number of years for which the firms had R&D units and the rate of growth of R&D expenditures in such units. Using the Department of Science and Technology's Research and Development Statistics, we calculated that real R&D expenditures per R&D unit in the pre-1975 period.grew at about 5 per cent per year and that

[21] See Hall and Mairesse (1992).

the average age of the R&D units was 4.7 years. Based on these calculations we assumed that the firms reporting positive R&D expenditures in 1975 had been doing R&D for 5 years prior to that year and that their R&D expenditures had grown by 5 percent per year in real terms. Thus the 1975 own-knowledge stock was calculated as:

$$KO_{75} = RD_{74}\ \Sigma_{s=0}{}^{4}[(1 - 0.15)/(1 + 0.05)]^{s} \qquad \text{(B.2)}$$

The sample firms report for each year their expenditures on foreign technology acquired through disembodied technology licenses. As in the case of R&D, the perpetual inventory method was used to construct the knowledge stocks, KP_{it}, generated from flows of technology purchase, TP_{it} :

$$KP_{it} = (1-\delta)KP_{it-1} + TP_{it-1} \qquad \text{(B.3)}$$

It was again assumed that δ is equal to 15 percent. Since the United States is the largest seller of technology to India, the flows of TP were deflated by the United States' R&D deflator obtained from Hall, et. al. (1988).

As in the case of R&D, the major problem was to compute the knowledge stocks generated from foreign technology purchases for the initial year of our data. This computation involved two basic steps. First, we identified the years in which each firm entered into a licensing agreement with a foreign firm using the Indian Investment Center's <u>Directory of Foreign Collaborations in India.</u>[22]

[22]In the absence of such information about firms' pre-sample technology purchases, Ferrantino (1992) assumed that the ratio of each firm's pre-sample technology purchases to its within sample technology purchases was the same as the ratio of the pre-sample to the within-sample, economy-wide R&D expenditures.

Assuming that the flow of technological information and payments for technology lasted four years,[23] the years in which these firms obtained technology flows were identified. Second, for firms which purchased technology during the 1965-1974 period, the average ratio of technology purchase expenditures to sales was computed for three-digit industry groups, using the firm-level information for the first year of data, 1975. These ratios were multiplied by each firm's sales in 1975 to provide an estimate of the payments for technology per year for any year during 1965-1974 in which the firm was known to have purchased technology as determined in Step 1 above. These pre-1975 payment streams were then discounted and depreciated in order to obtain KP, for the initial year, 1975. KP_{it} for subsequent years was obtained using equation (B.3).

[23] See Kapur (1983).

Appendix C: Construction of Soillover Variables

As mentioned earlier, the international spillover variable was constructed by weighting the R&D in industry j from country c according to its relevance to India, the weight being denoted by REL_{jc}. REX,, was constructed as the ratio of patents granted by India to inventors from industry j in country c to the ratio of patents granted by country c to inventors in industry j from country c. REL_{jc} was then normalized to add up to one within an industry j.

Clearly, in order to construct REL_{jc} we need to know the number of patents granted to inventors in each industry j. Unfortunately, such information is not readily available, for patent examiners normally assign to patents an International Patent Classification (IPC) which denotes only the technological area with which the patent is concerned, an area which may be of interest to several different industries. In order to obtain the patent-industry assignments which we desire, we employed the Yale Technology Concordance (YTC), a matrix constructed from data on 183,288 patents granted in Canada between 1978-1987 (Evenson, Kortum, and Putnam (1989)). When a patent is granted in Canada, examiners are required to assign one or more industries of manufacture (IOM) for the invention in addition to assigning the IPC code. By counting the number of occurrences of various IPC-IOM combinations, it is possible to construct empirical probabilities for the chances that a patent in IPC i is manufactured in industry j.

These probabilities were used to map patents granted by developed country c to inventors from country c into industry of manufacture j for the period 1972-1989, the total number of such patents being denoted by IOM_{jc}. We then mapped patents granted by India to inventors from country c into industry of manufacture j for the same period, the total number of such patents being denoted by iom_{jc}. REL_{jc} is then defined by:

$$REL_{jc} = iom_{jc}/IOM_{jc} \tag{C.1}$$

where we normalized REL_{jc} to add up to 1 within an industry j. The relevance-weighted, flow of foreign spillovers for each industry j at time t, denoted by SF_{jt}, is then defined by:

$$SF_{jt} = \sum_{c=1}^{8} REL_{jc} R_{jct} \tag{C.2}$$

where R_{jct} is the R&D of industry j in country c at time t. The flow of domestic spillovers for industry j at time t, SD_{jt}, was constructed as the sum of all R&D conducted by Indian firms in industry j at time t.[24]

The fact that REL_{jc} was constructed using the empirical probabilities of various IPC-IOM combinations instead of the true, unobserved probabilities introduces some errors; however, given the enormous number of patents used to make the concordance, the empirical probabilities should be close to their true values. What

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[24] Both the international and Indian R&D data were only available for 2-digit industries, while the firms could be placed into 3 1/2-digit industries; hence, we first disaggregated the 2-digit R&D data into 3 1/2-digit industrial categories by assuming that the R&D-patent ratio is constant within a 2-digit category and then multiplying the 2-digit, R&D-patent ratio by the number of patents granted to each 3 1/2-digit industry. See Fikkert (1994) for details.

is perhaps more problematic is that we are using a concordance constructed with Canadian data to map patents granted in 8 developed and one less developed country. Differences in technological relationships or in industry sizes across countries will introduce errors in the construction of these variables. However, we feel that this procedure is superior to the alternative in which the R&D from every country is treated as equally relevant.

It ii3 still necessary to convert the domestic and international spillover flows into spillover stocks. Following Hall and Mairesse (1992), the stocks in the initial year were obtained by assuming that the pre-sample international and domestic spillover pools in industry j grew at the annual rates of g_{fj} and g_{dj} respectively. Thus it is possible to write:

$$KD_{j0} = SD_{j0}\sum_{s=0}^{\infty}\left[\frac{1-\delta}{1+g_{dj}}\right]^{s} = \frac{SD_{j1}}{g_{dj}+\delta} \qquad (C.3)$$

and

$$KF_{j0} = SF_{j0}\sum_{s=0}^{\infty}\left[\frac{1-\delta}{1+g_{fj}}\right]^{s} = \frac{SF_{j1}}{g_{fj}+\delta} \qquad (C-4)$$

where 6 is the depreciation rate, assumed to be 15 percent, and g_{dj} and g_{fj} were uniquely computed for each industry from the flow data (i.e. SD,, and SF,,) for the 1975-1980 period. Finally, each firm's own-R&D' stock, KO_{it}, was subtracted from its domestic spillover stock, KD_{jt}, in order to arrive at a stock of domestic, spillover R&D for each firm i, KD_{it}, which is solely performed by the other firms within firm i's industry.